

Site Evaluation for Application of Fuel Cell Technology

U.S. Coast Guard Air Station Cape Cod, MA

Michael J. Binder, Franklin H. Holcomb, William R. Taylor, J. Michael Torrey, and John F. Westerman

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Foreword

This study was conducted for the U.S. Coast Guard (U.S.C.G.) Air Station Cape Cod, MA under Military Interdepartmental Purchase Request (MIPR) No. W31RY-O83360270, Work Unit V69, "New TI Design of PAFC Power Plants." The technical monitor was Steve Allen, U.S. Coast Guard R&D Center.

Jim Candee, of the U.S.C.G. Research and Development Center, was the primary point of contact for the site visits, provided contact with appropriate site personnel, and collected various needed information such as energy bills, site drawings, etc. His efforts were instrumental in completing this site evaluation. In addition, David Cleveland and Bob Minervino provided important information about facility operation.

This report documents work done at the U.S. Coast Guard Air Station, Cape Cod, MA. The work was performed by the Energy Branch (CF-E), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Michael J. Binder. Part of this work was done by Science Applications International Corporation (SAIC) under. contract No. DACA88-98-003. J. Michael Torrey and John F. Westerman are associated with SAIC. The technical editor was William J. Wolfe, Information Technology Laboratory. Larry M. Windingland is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Gary W. Schanche. The Acting Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John Morris III, EN and the Director of ERDC is Dr. James R. Houston.

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1 Introduction

Background

Fuel cells generate electricity through an electrochemical process that combines hydrogen and oxygen to generate direct current (DC) electricity. Fuel cells are an environmentally clean, quiet, and a highly efficient method for generating electricity and heat from natural gas and other fuels. Air emissions from fuel cells are so low that several Air Quality Management Districts in the United States have exempted fuel cells from requiring operating permits. Today's natural gas-fueled fuel cell power plants operate at electrical conversion efficiencies of 40 to 50 percent; these efficiencies are predicted to climb to 50 to 60 percent in the near future. In fact, if the heat from the fuel cell process is used in a cogeneration system, efficiencies can exceed 85 percent. By comparison, current conventional coal-based technologies operate at efficiencies of 33 to 35 percent.

Phosphoric Acid Fuel Cells (PAFCs) are in the initial stages of commercialization. While PAFCs are not now economically competitive with other more conventional energy production technologies, current cost projections predict that PAFC systems will become economically competitive within the next few years as market demand increases.

Fuel cell technology has been found suitable for a growing number of applications. The National Aeronautics and Space Administration (NASA) has used fuel cells for many years as the primary power source for space missions and currently uses fuel cells in the Space Shuttle program. Private corporations have recently been working on various approaches for developing fuel cells for stationary applications in the utility, industrial, and commercial markets. Researchers at the U.S. Army Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL) have actively participated in the development and application of advanced fuel cell technology since fiscal year 1993 (FY93). CERL successfully executed several research and demonstration work units with a total funding of approximately \$55M.

CERL researchers have developed a methodology for selecting and evaluating application sites, have supervised the design and installation of fuel cells, and have actively monitored the operation and maintenance of fuel cells, and com-

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piled "lessons learned" for feedback to manufacturers. This accumulated expertise and experience has enabled CERL to lead in the advancement of fuel cell technology through major efforts such as the DoD Fuel Cell Demonstration, the Climate Change Fuel Cell Program, research and development efforts aimed at fuel cell product improvement and cost reduction, and conferences and symposiums dedicated to the advancement of fuel cell technology and commercialization.

This report presents an overview of the information collected at the U.S. Coast Guard Air Station Cape Cod, MA, along with a conceptual fuel cell installation layout and description of potential benefits the technology can provide at that location.

Objective

The objective of this work was to evaluate the U.S. Coast Guard Air Station Cape Cod as a potential location for a fuel cell application.

Approach

On 29 and 30 October 1998, CERL and SAIC representatives visited the United States Coast Guard (U.S.C.G.) Air Station Cape Cod to investigate it as a potential location for a 200 kW fuel cell. This report presents an overview of information collected at the site along with a conceptual fuel cell installation layout and description of potential benefits. A copy of the site evaluation form filled out at the Air Station is provided as an addendum to this report.

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

```
1 ft = 0.305 m

1 mile = 1.61 km

1 acre = 0.405 ha

1 gal = 3.78 L

°F = °C (X 1.8) + 32
```

2 Site Description

The U.S.C.G. Air Station Cape Cod (A.S.C.C.) is located within the Otis Air National Guard Base in Cape Cod, MA. A.S.C.C. is situated on 22,000 acres and is host to the Air Force Pave Paws site, Massachusetts Army National Guard, 102nd Air Force Reserve Squadron, and several other Federal agencies. A.S.C.C. consists of nearly 50 nonresidential buildings plus over 600 housing units. A.S.C.C. crews fly both HH60J "JayHawk" Helicopters and HU-25 "Falcon" Jets, which perform a variety of Coast Guard missions. Its primary mission, Search and Rescue (SAR), involves the protection of life and property in the offshore areas from the Canadian border to Long Island. In addition, A.S.C.C. plays a major role in maritime law enforcement, fisheries enforcement patrols, marine environmental protection, international ice patrols, drug interdiction, and logistics support for the many offshore lighthouses in New England.

A.S.C.C. is comprised of two main areas: the air station hangars, taxiway and related buildings (Air Station), and a larger section of the base that contains the bulk of the housing, a medical clinic, exchange, theatres, etc. (Main Base). These two areas are served by different electric utilities.

The ASHRAE design temperatures for the site are 14 and 79 °F. Extreme temperatures range from 11 to 85 °F.

Early in this study, it was determined that the focus of the A.S.C.C. fuel cell evaluation would be at the Air Station (i.e., the area adjacent to the taxiway). None of the housing, medical clinic or other buildings in the Main Base area had thermal loads large enough to utilize the fuel cell's thermal output. Therefore, the focus of the report was shifted to the Air Station.

The Bachelor Officer Quarters/Bachelor Enlisted Quarters (BOQ/BEQ) was identified as the primary candidate site at the Air Station. An office area located inside one of the hangars was evaluated, but it was determined that the thermal load was strictly a small seasonal heating load and was therefore eliminated from detailed consideration. Other buildings within the Air Station had little if any thermal load.

Site Layout

Figure 1 shows a site map of the Air Station including various buildings and the taxiway area.

Building 3159 is a BOQ/BEQ facility and also houses a galley. It was built in 1970 and was acquired by the U.S.C.G. in 1992. The 36,700 sq ft building has three floors, plus a basement and mechanical rooms. It is constructed of block and brick fascia. During the site visit, an external wall insulation material was being installed (Dryvitt or similar material) to address the building leakage issues. The building currently has the capacity for 69 people to stay overnight. There are 28 permanent party rooms (single), 9 double and 5 single student rooms, and 18 single duty personnel quarters.

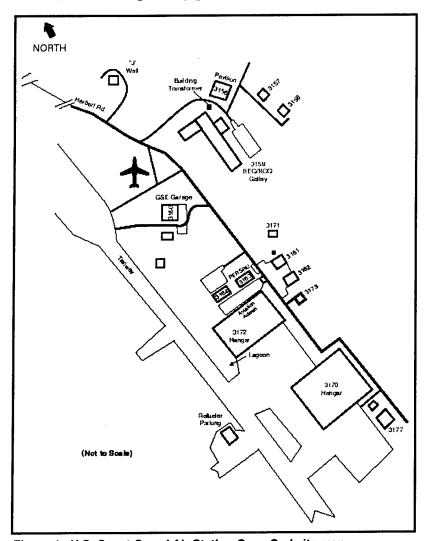


Figure 1. U.S. Coast Guard Air Station Cape Cod site map.

Electrical System

Electricity at the A.S.C.C is provided by two electric utilities. Narragansett Electric serves the Main Base and all of the Otis Air National Guard site except for the Air Station. The U.S.C.G pays Otis Air National Guard for the Main Base portion of the electric bill. The Air Station is served by COM Electric through a 1000 kVA transformer located on the south side of the Air Station.

At Building 3159, there is a 208/4160 V, 300 kVA transformer located outside near the northwest corner the building. Currently there is no 480 V power at Building 3159. To interface with the fuel cell, a new 480 V transformer would need to be installed and connected to either the 208 V side of the existing transformer or directly into the 4160 V grid.

Steam/Hot Water System

There are currently two steam boilers located in the Building 3159 mechanical room (Figure 2). One is a Kewanee 5 MMBtu/hr, and the other is a 320,000 Btu/hr Weil-McLain boiler. Steam is generated at 11 psig. The Kewanee boiler is used during the space heating season (October-April), and the smaller Weil-McLain boiler is used during the summer months. Steam is used in the building to generate domestic hot water (DHW) for the rooms and the galley as well as to heat the hydronic space heating loop. Steam also is used in the galley directly for heating cooking kettles and in the Hobart dishwashing unit. There is a 1,600 gal hot water storage tank that is currently set to a temperature of 160 °F. The 160 °F temperature is higher than normal for DHW purposes, but is specified for use in the Hobart dishwasher. (Note that the Hobart dishwasher electrically boosts the 160 °F temperature up to 180 °F.)

Space Heating System

Space heating is provided through a hydronic loop that runs throughout Building 3159. A steam-to-hot water shell and tube heat exchanger is located in the mechanical room.

Space Cooling System

Currently there is no air conditioning in Building 3159, but there are plans for a system to be installed in the near future.

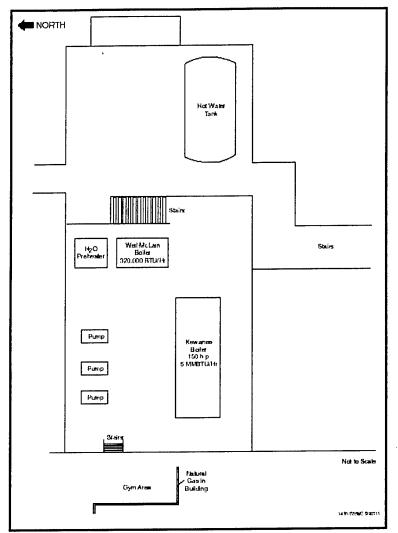


Figure 2. Building 3159 mechanical room layout.

Fuel Cell Location

The fuel cell should be sited on the south side of Building 3159 (Figure 3). The fuel cell should run east-west with the thermal outlet side facing the mechanical room. The cooling module can be located next to the fuel cell in a north-south direction. Nitrogen tanks can be placed against the mechanical room wall.

The thermal piping from the fuel cell to the mechanical room will be approximately 15 ft for the low grade loop. A high grade heat loop would be needed to interface with the space heating loop. The thermal piping run would be ~30 ft. Natural gas should be tied into the main gas line running through the building (~40 ft extension). The make-up water can be taken from inside the building (~15 ft). The electrical run will be ~100 ft to the new transformer to be located next to the existing transformer. The cooling module piping run is ~20 ft.

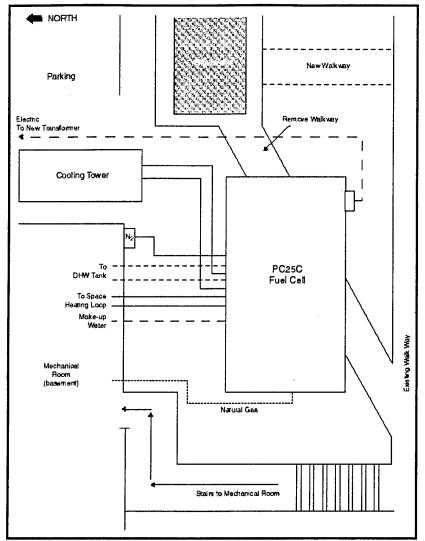


Figure 3. Fuel cell location and interfaces.

Fuel Cell Interfaces

Electrical Interface

There is a 208/4160 V, 300 kVA transformer located outside the building on the northwest corner. There are no electric loads within the building that are the same voltage as the fuel cell output of 480 V. To provide an appropriate electrical interface for the fuel cell, a new 300 kVA transformer will be required. The new transformer can be 480/4160 V and interface with the high voltage side of the existing transformer, or the new transformer can be 480/208 V and interface with the low voltage side of the transformer, which connects to the main bus bar of Building 3159. The electric load at Building 3159 is expected to drop below

the nominal 200 kW of the fuel cell at certain times. Fuel cell electric output not used at Building 3159 would be fed back to the Air Station grid.

The peak demand for the Air Station ranged from a low of 355 kW to high of 440 kW during the last year. Interval load data was provided by COM Electric for the transformer that serves the entire Air Station load (Table 1). These data indicate that the Air Station total load falls below the fuel cell's 200 kW output only 0.2 percent of the time. Output loads between 201–250 kW occur only 1.6 percent of the time.

A special meter should be installed so that, when the total load of the Air Station drops to approximately 230 kW, the fuel cell would incrementally drop its load output by a set amount. This will ensure that the fuel cell never exports electricity to the COM Electric utility grid.

Thermal Interface

The two major thermal loads within Building 3159: are: (1) Domestic Hot Water (DHW), and (2) space heating. Heat is generated for both of these loads by two steam boilers. One boiler has a capacity of 5 MMBtu/hr and is used primarily during the winter months. The second boiler has a capacity of 320,000 Btu/hr and is used as the primary heating source in the summer. Both of the thermal loads are analyzed below to determine their viability for utilizing fuel cell heat.

Domestic Hot Water Heating Requirements

The DHW system consists of a 1600-gal storage tank, which is heated by either of the two steam boilers. The hot water is used for showers, hand sinks, laundry, and a kitchen. The set point temperature for the storage tank currently is 160 °F to accommodate temperature requirements for kitchen equipment.

Table 1. Air station electric load data.

	Hours by kW Demand Group				
•	0–200	201–250	> 250	All	
01May97-31Jul97	25.3	29.0	2,153.8	2,208	
01Aug97-30Sep97	-	28.5	1,435.5	1,464	
01Oct97-31Dec97	3.0	36.5	2,168.5	2,208	
01Jan98-31Mar98		28.8	2,131.3	2,160	
01Apr98 - 30Jun98		62.5	2,121.5	2,184	
01Jul98 – 31Aug98			1,488.0	1,488	
Total Hours	28	185	11,499	11,712	
Percent of Total Hours	0.2%	1.6%	98.2%	100.0%	

There are two circulating loops from the storage tank. One loop is 160 °F and supplies the kitchen, and the other loop is 140 °F and supplies hot water for the other DHW loads. Figure 4 shows the existing DHW system configuration.

For the purposes of this analysis, the DHW loads are separated into the non-kitchen loads and the kitchen loads. To estimate the contribution of the fuel cell for supplemental heating of the DHW system, the following inputs and assumptions are used:

- The facility is occupied 24 hours per day, 365 days per year.
- The makeup of the occupants using the facility is 75 percent male and 25 percent female.
- 95 percent of the occupants use the facility each day.
- The average temperature of the cold water makeup is 60 °F.
- The DHW temperature set point is 160 °F.
- Non-kitchen DHW loads use 140 °F water.

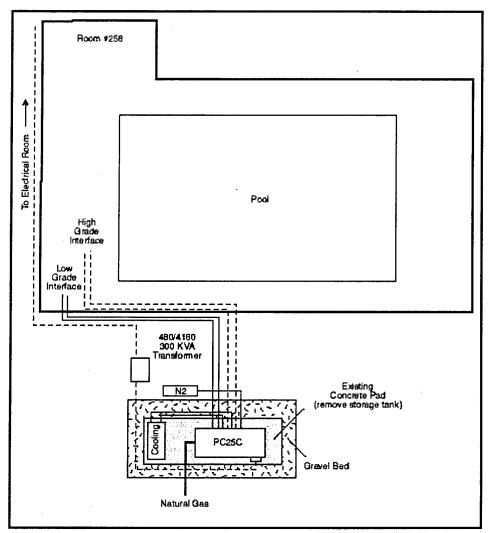


Figure 4. Roland Hall fuel cell location and interfaces.

Using hot water demand reference data from the 1991 ASHRAE Applications Handbook (Chapter 44, "Service Water Heating"), the closest description to Building 3159 is a dormitory that consists of showers, lavatories, service sinks, and washing machines. On average, hot water demand is estimated to be 13.1 gal/occupant/day for men and 12.3 gal/occupant/day for women. Assuming that the mix of occupants is 75 percent male and 25 percent female, an average daily rate of hot water consumption of 12.9 gal/occupant/day was used.

12.9 gal/occupant/day = [(75% x 13.1 gal/occupant/day) + (25% x 12.3 gal/occupant/day)]/100%

Assuming an occupancy load factor of 95 percent, the average heating rate required to heat the makeup water (12.9 gal/occupant/day) and maintain the storage temperature at 160 °F at all times is 29,349 Btu/hr.

29,349 Btu/hr =66 occupants/day x 12.9 gal/occ/day x 8.33 lb/gal x 1 Btu/lb °F x (160–60) °F 24 hours/day

In addition to the makeup water heating requirement, heating is required to compensate for losses due to the DHW recirculation loop. The recirculation losses are estimated as follows:

•	Flow Rate:	20 gpm
•	Supply Temperature:	140 °F
•	Return Temperature (winter):	125 °F
•	Return Temperature (summer):	135 °F.

The resulting loss in the winter is 149,940 Btu/hr:

```
20 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x (140 - 125) °F x 60 min/hr
```

The resulting loss in the summer is 49,980 Btu/hr:

```
20 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x (140 - 135) °F x 60 min/hr
```

Note that the only difference between the winter and summer recirculation losses is the estimated return temperature.

To estimate the annual demand for the non-kitchen DHW, the above rate of heating is assumed to be constant throughout the year. That is to say, usage of the facility is fairly constant from one month to the next. Table 2 lists the monthly consumption.

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Table 2. Building 3159 non-kitchen DHW load.

Month	Operation: Days/Month	Recirculation Losses (kBtu/hr)	Recirculation Losses (kBtu/mo)	Makeup Water (kBtu/mo)	kBtu/mo
January	31	149.9	111,555.4	21,835.8	133,391.2
February	28	149.9	100,759.7	19,722.7	120,482.3
March	31	149.9	111,555.4	21,835.8	133,391.2
April	30	149.9	107,956.8	21,131.4	129,088.2
May	31	50.0	37,185.1	21,835.8	59,020.9
June	30	50.0	35,985.6	21,131.4	57,117.0
July	31	50.0	37,185.1	21,835.8	59,020.9
August	31	50.0	37,185.1	21,835.8	59,020.9
September	30	50.0	35,985.6	21,131.4	57,117.0
October	31	149.9	111,555.4	21,835.8	133,391.2
November	30	149.9	107,956.8	21,131.4	129,088.2
December	31	149.9	111,555.4	21,835.8	133,391.2
Total	365		946,421.3	257,098.9	1,203,520.2

The total available thermal output from the fuel cell during the year is 6,132,000 kBtu (700 kBtu/hr x 24 Hours/Day x 365 Days/Year). Therefore, the DHW load represents a thermal utilization of 19.6 percent (1,203,520 / 6,132,000).

To estimate the hot water demand for the kitchen, reference data was utilized from the 1991 ASHRAE Applications Handbook (Chapter 44, "Service Water Heating"). Data is presented for two categories of service as follows:

1. Full meal restaurants and cafeterias: 2.4 gal/meal

2. Grills, sandwich shops and snack shops: 0.7 gal/meal.

Data provided on kitchen usage indicates that two types of meals are typically prepared: meals in the galley and flight meals (e.g., box lunches). For purposes of this analysis, meals in the galley were assumed to use 2.4 gal/meal and flight meals were assumed to use 0.7 gal per meal. Using meal data provided by A.S.C.C, water usage was calculated using the above assumptions for two months as presented in Table 3.

These data are used to develop an annual demand profile for the kitchen DHW load. Note that the data for the 2 months presented above were provided by the Air Station and that the individual monthly load factors shown below were changed to establish a transition from July to November and November to July. To estimate the average hourly rate of heating required, it was assumed that the kitchen operates an average of 12 hours per day. The annual demand is presented in Table 4.

Table 3. Kitchen hot water usage estimates.

	Meal Type	Number of Meals	gal/meal	gal/month	gal/day
	Galley	5,077.0	2.4	12,184.8	393.1
马	Flight	1,512.0	0.7	1,058.4	34.1
	Total	6,589.0	·	13,243.2	427.2
	Galley	2,997.0	2.4	7,192.8	232.0
Nov.	Flight	1,296.0	0.7	907.2	29.3
-	Total	4,293.0		8,100.0	261.3

Table 4. Building 3159 kitchen DHW load.

Month	Operation (days/mo)	Operation (hr/mo)	Occupant Load Factor	Meals/day	gal/day	kBtu/hr	kBtu/mo
January	31	372	61%	109	261.3	21.8	8,095.7
February	28	336	61%	109	261.3	21.8	7,312.3
March	31	372 ·	70%	125	299.1	24.9	9,267.4
April	30	360	95%	169	405.9	33.8	12,171.4
May	31	372	100%	178	427:2	35.6	13,239.1
June	30	360	100%	178	427.2	35.6	12,812.0
July	31	372	100%	178	427.2	35.6	13,239.1
August	31	372	95%	169	405.9	33.8	12,577.2
September	30	360	90%	160	384.5	32.0	11,530.8
October	31	372	82%	146	350.3	29.2	10,856.1
November	30	360	61%	109	261.3	21.8	7,834.6
December	31	372	61%	109	261.3	21.8	8,095.7
Total	365	4,380					127,031.4

In addition to the makeup water heating requirement, heating is required to compensate for losses due to the kitchen DHW recirculation loop. The recirculation losses are estimated as follows:

Flow Rate: 20 gpm
Supply Temperature: 160 °F
Return Temperature (winter): 150 °F
Return Temperature (summer): 155 °F.

The resulting loss in the winter is 99,960 Btu/hr:

20 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x (160 - 150) °F x 60 min/hr

The resulting loss in the summer is 49,980 Btu/hr:

20 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x (160 - 155) °F x 60 min/hr

Table 5.	Recirculation	losses for	Building 3	159 kitchen	DHW load.
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Month	Operation (days/mo)	Recirculation Losses (Btu/hr	Recirculation Losses (Btu/mo)	.Makeup Water (Btu/mo)	kBtu/mo
January	31	100.0	74,370.2	8,095.7	82,466.0
February	28	100.0	67,173.1	7,312.3	74,485.4
March	31	100.0	74,370.2	9,267.4	83,637.6
April	30	100.0	71,971.2	12,171.4	84,142.6
Мау	31	50.0	37,185.1	13,239.1	50,424.2
June	30	50.0	35,985.6	12,812.0	48,797.6
July	31	50.0	37,185.1	13,239.1	50,424.2
August	31	50.0	37,185.1	12,577.2	49,762.3
September	30	50.0	35,985.6	11,530.8	47,516.4
October	31	100.0	74,370.2	10,856.1	85,226.3
November	30	100.0	71,971.2	7,834.6	79,805.8
December	31	100.0	74,370.2	8,095.7	82,466.0
Total	365		692,123.0	127,031.4	819,154.5

Note again that the only difference between the winter and summer recirculation losses is the estimated return temperature.

To estimate the annual demand for the kitchen DHW, the above rate of makeup water and recirculation losses were combined. The monthly consumption is presented in Table 5. The fuel cell thermal use for the kitchen DHW totals 13.4 percent (819,154/6,132,000).

To verify that the estimates for the DHW presented above are reasonable, the summer gas requirements were compared to the historical summer gas bills. Summer months were analyzed since there would not be any gas consumption for space heating during this time period. July billing data indicates that 174,500 cu ft were consumed. DHW estimates for July make-up and recirculation requirements are 109,441 kBtu (59,020.9 + 50,424.2). Assuming a boiler efficiency of 75 percent, the natural gas requirement to meet this load is 150,229 cu ft.

150,229 cu ft = 109,441 kBtu/Month x (1 cu ft/ 1.00 kBtu) x (1/0.75)

This leaves 24,271 cu ft (174,500 - 150,229) of natural gas for kitchen equipment requirements. Therefore the estimates are within the historical consumption rates for natural gas and are reasonable.

Since the return temperature from the kitchen is estimated to be approximately 145 to 155 °F, the high grade heat exchanger option would be required to ac-

commodate this load. The maximum capacity of the high grade heat exchanger is 350,000 Btu/hr. To take advantage of the maximum benefit of the fuel cell thermal output, a control strategy needs to be incorporated that will give priority to the fuel cell for heating the storage tank. The storage tank set point temperature should remain at 160 °F, but the steam loop control to begin heating should be lowered. Thus, as long as the fuel cell can keep up with the heating requirement, the steam will not come on. In the case where the DHW demand significantly exceeds the fuel cell capacity (i.e., the storage tank temperature falls below 150 °F), the steam will come on and heat the tank to 160 °F.

The thermal interface for the DHW tank (160 °F) is presented in Figure 5. The non-kitchen recirculation loop is serviced by the fuel cell low grade heat exchanger, and the kitchen recirculation loop is serviced by the fuel cell high grade heat exchanger.

Another option for integrating the fuel cell to the DHW storage tank is to lower the tank temperature from 160 to 140 °F. Discussions with the kitchen personnel revealed that the only reason for the 160 °F water was for the Hobart dishwasher. The Hobart has an internal heater that further boosts this temperature to 180 °F. By lowering the storage tank temperature, energy savings can be achieved through reduced recirculation losses and by lowering the temperature differential between the incoming makeup water and the storage tank set point.

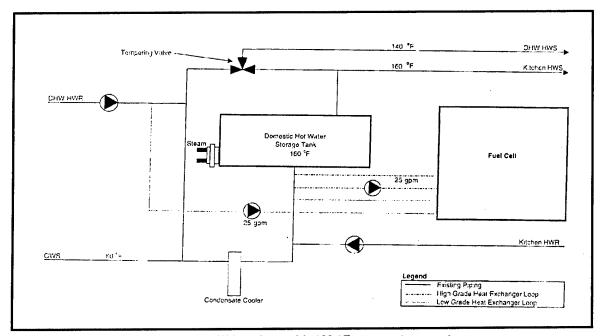


Figure 5. Building 3159 fuel cell DHW interface with 160 °F storage temperature.

This also has an impact on the fuel cell integration in that it would eliminate the requirement for a high grade heat exchanger for the DHW high temperature load. This option is explored below based on the following assumptions:

- Storage Set Point Temperature: 140 °F

• Kitchen Load:

Flow Rate: 20 gpm
 Supply Temperature: 140 °F
 Return Temperature (winter): 130 °F
 Return Temperature (summer): 135 °F

• Non-kitchen:

Flow Rate: 20 gpm
 Supply Temperature: 140 °F
 Return Temperature (winter): 125 °F
 Return Temperature (summer): 130 °F

Tables 6 and 7 list the resulting hot water loads.

The resulting annual thermal recovery for interfacing the fuel cell with the 140 °F storage tank is 1,928,911 kBtu (1,152,100 + 776,811). This represents a thermal utilization of 31.5 percent (1,928,911 / 6,132,000). The fuel cell interface is presented in Figure 6 for the case in which no high grade heat exchanger is required.

Table 6. Building 3159 non-kitchen DHW load.

Month	Operation Days/mo	Recirculation Losses (kBtu/hr)	Recirculation Losses kBtu/mo	Makeup Water (kBtu/mo)	kBtu/mo
January	31	149.9	111,555.4	17,468.6	129,024.0
February	28	149.9	100,759.7	15,778.1	116,537.8
March	31	149.9	111,555.4	17,468.6	129,024.0
April	30	149.9	107,956.8	16,905.1	124,861.9
Мау	31	50.0	37,185.1	17,468.6	54,653.8
June	30	50.0	35,985.6	16,905.1	52,890.7
July	31	50.0	37,185.1	17,468.6	54,653.8
August	31	50.0	37,185.1	17,468.6	54,653.8
September	30	50.0	35,985.6	16,905.1	52,890.7
October	31	149.9	111,555.4	17,468.6	129,024.0
November	30	149.9	107,956.8	16,905.1	124,861.9
December	31	149.9	111,555.4	17,468.6	129,024.0
Total	365		946,421.3	205,679.1	1,152,100.4

Month	Operation (days/mo)	Recirculation Losses (kBtu/hr)	Recirculation Losses (kBtu/mo)	Makeup Water (kBtu/mo)	kBtu/mo
January	31	100.0	74,370.2	5,397.1	79,767.4
February	28	100.0	67,173.1	4,874.8	72,048.0
March	31	100.0	74,370.2	6,178.3	80,548.5
April	30	100.0	71,971.2	8,114.3	80,085.5
May	31	50.0	37,185.1	8,826.1	46,011.2
June	30	50.0	35,985.6	8,541.4	44,527.0
July	31	50.0	37,185.1	8,826.1	46,011.2
August	31	50.0	37,185.1	8,384.8	45,569.9
September	30	50.0	35,985.6	7,687.2	43,672.8
October	31	100.0	74,370.2	7,237.4	81,607.6
November	30	100.0	71,971.2	5,223.0	77,194.2
December	31	100.0	74,370.2	5,397.1	79,767.4
Total	365		692,123.0	84,687.6	776,810.6

Table 7. Recirculation losses for Building 3159 non-kitchen DHW load.

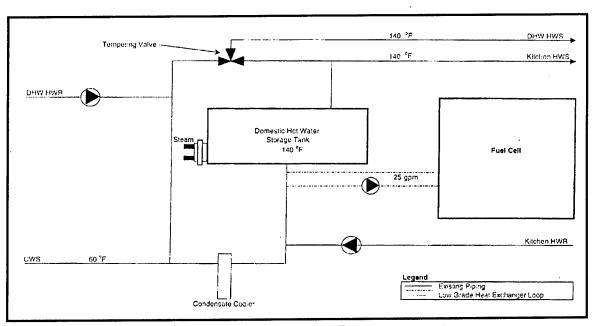


Figure 6. Building 3159 fuel cell DHW interface with 140 °F storage temperature.

Space Heating Requirements

Providing space heating to the building using heat recovered from the fuel cell also was evaluated. The temperature set point for the heating hydronic loop is variable. The set point control scheme is to provide 180 °F water when the outdoor dry bulb temperature is 0 °F. The set point is then lowered \sim 5 °F for each 1 °F increase in the outdoor temperature. To accommodate the times when the

high temperature water is required, the fuel cell would need to be purchased with the high grade heat exchanger option. To estimate the heating load of the building, the U-value for the various building envelope components were estimated from previous base energy studies. Table 8 lists the design day heating load for Building 3159.

Historical temperature bin data was used to estimate the annual potential fuel cell heat recovery for space heating. The bin data was obtained from a software package developed by the Gas Research Institute (GRI) called "BinMakerTM: The Weather Summary Tool." BinMakerTM data is based on TMY-2 data gathered by the National Renewable Energy Laboratory in Golden, CO. Table 9 lists the monthly hours of heating required for the building, based on outdoor dry bulb temperature.

To estimate the average building heating load during each month, the average outdoor temperature was substituted for the winter design temperature input in Table 8 to get the heating load calculation result. Since the resulting average building heating load is greater than the high grade heat exchanger capacity, it is assumed that the full capacity of the high grade heat will be utilized during the hours of heating demand. Table 10 lists the estimated monthly space heating requirement. The space heating load represents a fuel cell thermal utilization of 20.9 percent (1,283,450 / 6,132,000).

Table 8. Building 3159 space heating load calculations.

Design Conditions					
Floor area	36700 sq ft				
Winter design temperature	14 Dry Bulb				
Indoor design temperature	70 Dry Bulb				
Transmission					
Description	Area	U-Value	Factor	Delta-T	Btu/Hr
Glazing: dual	4446.0	0.57	1	56	141,916
Wall	13087.0	0.27	1.18	56	233,493
Ceiling	6460.0	0.05	1.18	56	21,344
Floor: slab perimeter	416.0	0.9	1	28	10,483
Sub-Total					407,236
Infiltration					
Description	Area	Height	Factor	Delta-T	Btu/hr
	36700	8.5	0.018	56	314,446
Duct Losses					
Percent of load		10%		ľ	72,168
Total hourly heat loss (Btu/Hr)					793,850

Table 9. Weather bin data for Cape Cod.

Month	Hours	Avg. Temp. (°F)
January	723	28.9
February	661	31.0
March	642	34.4
April	422	40.7
May	31	42.5
June	0	
July	0	_
August	0	_
September	0	
October	102	43.5
November	469	37.3
December	617	30.9

Table 10. Building 3159 space heating load estimates.

Month	Hours of Heating	Average Building Load (kBtu/hr)	Average Fuel Cell Contribution (kBtu/hr)	Monthly Heat Recovered (kBtu)
January	723	582.6	350	253,050
February	661	552.9	350	231,350
March	642	504.7	350	224,700
April	422	415.4	350	147,700
May	31	389.8	350	10,850
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	. 0
October	102	375.7	350	35,700
November	469	463.6	350	164,150
December	617	554.3	350	215,950
Total	3,667.0			1,283,450

The ONSI literature indicates that the high grade heat exchanger is capable of providing 350,000 Btu/hr with an inlet temperature of 160 °F. The fuel cell interface would be made on the return water piping of the hot water loop. Figure 7 shows the fuel cell interface to preheat the hot water return for space heating. A 25 gpm pump would pull 160 °F water from the loop and pass it through the fuel cell. The fuel cell with a maximum high temperature heating capacity of 350,000 Btu/hr would then heat the water to 188 °F. The 188 °F water would then be introduced back into the return water loop where the mixed temperature entering the steam to hot water heat exchanger would be 171.7 °F.

171.7 °F = ((25 gpm x 160 °F) + (5 gpm x 188 °F)) / 60 gpm 188 °F = 160 °F + 350,000 Btu/hr (25 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x 60 min/hr)

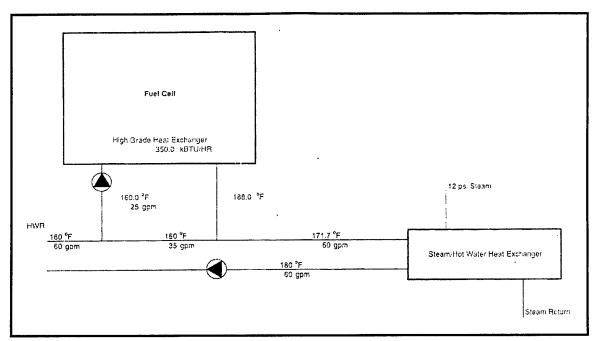


Figure 7. Building 3159 space heating loop heating recovery.

As previously noted, interfacing with the kitchen DHW while maintaining a storage tank temperature at 160 °F and the space heating loads will require the high grade heat exchanger option on the fuel cell. If both of these loads are interfaced to the fuel cell, there are two implications:

- 1. The total kitchen demand and the space heating demand as previously estimated are not additive because the combined loads will exceed 350,000 kBtu/hr at certain times. Table 11 lists the estimated fuel cell heating contributions if all three heating loads are integrated to the fuel cell. This estimate assumes that the space heating load is satisfied first. The kitchen load is estimated by subtracting space heating hours in the month from the month hours and multiplying by the average kitchen Btu/hr. This is only a method of estimating the load and is not a model of operation. The resulting thermal utilization is 45.9 percent (2,814,089 / 6,132,000).
- 2. An intermediate heat exchanger will be required to prevent mixing potable water with the space heating water. The intermediate heat exchanger will impact supply temperatures and require an additional pump.

Note that, under fuel cell operation, the thermal loads associated with the high grade heat exchanger have a higher priority than the loads from the low grade heat recovery heat exchanger since the two heat exchangers are piped in series within the fuel cell.

Table 11. Space heating load for combined interface loads.

Month	Non-Kitchen DHW (kBtu)	Kitchen DHW (kBtu)	Space Heating (kBtu)	Total
January	133,391.2	2,099.2	253,050.0	388,540.3
February	120,482.3	1,099.6	231,350.0	352,931.9
March	133,391.2	10,195.9	224,700.0	368,287.1
April	129,088.2	29,788.1	147,700.0	306,576.3
May	59,020.9	35,635.7	10,850.0	105,506.7
June	57,117.0	35,985.6	0.0	93,102.6
July	59,020.9	37,185.1	0.0	96,206.0
August	59,020.9	37,185.1	0.0	96,206.0
September	57,117.0	35,985.6	0.0	93,102.6
October	133,391.2	64,174.3	35,700.0	233,265.5
November	129,088.2	25,090.0	164,150.0	318,328.2
December	133,391.2	12,694.9	215,950.0	362,036.1
Total	1,203,520.2	327,119.1	1,283,450.0	2,814,089.3

Alternatively, lowering the storage tank temperature to 140 °F will eliminate the need for the high grade heat exchanger for the DHW storage tank. Thus, the combined DHW and space heating loads will result in a thermal utilization of 52.4 percent (31.5 + 20.9).

Summary of Thermal Interface Options

Maintaining the DHW storage tank temperature at 160 °F and supplying heat to the recirculation loops requires that a high grade heat exchanger be purchased with the fuel cell. If the DHW storage tank temperature is lowered to 140 °F, then a high grade heat exchanger will not be required for the DHW loads. A high grade heat exchanger will be required for interfacing with the space heating loop. Table 12 lists a summary of the options discussed along with their respective displaced thermal energy and fuel cell thermal utilization.

Natural Gas Interface

Building 3159 has an existing 4-in. natural gas pipeline up to the west wall of the mechanical room. The pressure of the gas line is 8-in. wc. The natural gas supply for the fuel cell would be a 2-in. pipe tapped off the 4-in. line and run to the location of the fuel cell through the mechanical room. If the pressure is not enough for the fuel cell, then a new gas line will have to be brought in from the north side of the building.

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Table 12. Summary of thermal energy savings scenarios.

Thermal Load Application (DHW Tank Temp. Set Point)	Fuel Cell Heat Exchanger	Displaced Thermal (kBtu/yr)	Thermal Utilization (%)
Kitchen DHW only (160 °F)	High Grade	819,154	13.4
Non-kitchen DHW only (160 °F)	Low Grade	1,203,520	19.6
Both Kitchen/Non-kitchen (160 °F)	High/Low	2,022,674	33.0
Both Kitchen/Non-kitchen (140 °F)	Low Grade	1,928,911	31.5
Space Heating Only (n/a)	High Grade	1,283,450	20.9
DHW/Space Heat (160°F)	High/Low	2,814,089	45.9
DHW/Space Heat (140°F)	High/Low	3,212,361	52.4

3 Economic Analysis

Electricity is provided to the A.S.C.C by two electric utilities: Narragansett Electric for the Main Base and COM Electric for the Air Station. The A.S.C.C pays the Otis Air National Guard Base directly under a sub-metering arrangement for electricity delivered by Narragansett. COM Electric provides electricity to the Air Station under rate schedule Medium General Time-of-Use (TOU)—Rate G-2. This time-of-use rate schedule is divided into three periods as shown in Table 13.

Table 13. Air Station Time-of-Use (TOU)—Rate G-2 Schedule.

Period	Daylight Savings Time	Eastern Standard Time
Peak (MonFri.)	9 a.m. – 6 p.m.	4 p.m.– 9 p.m.
Low A (MonFri.)	7 a.m 9 a.m. + 6 p.m10 p.m.	7 a.m. – 4 p.m. + 9 p.m.–10 p.m.
Low B	Remaining weekday hours plus weekends/holidays	Remaining weekday hours plus weekends/holidays

Electric bills for 1997 are summarized in Table 14. The peak billing demand ranged from 355 kW to 440 kW.

Table 14. Air Station electric billing data—COM Electric.

Month	Peak kW	Total kWh	Peak Period kWh	Low Period A kWh	Low Period B kWh	Billed Amount \$
Jan-97	381	218,700	36,376	73,456	108,868	\$20,798
Feb-97	411	230,400	39,997	82,985	107,418	\$21,909
Mar-97	377	203,400	32,794	66,750	103,856	\$19,409
Apr-97	362	189,180	46,699	51,545	90,936	\$18,213
May-97	410	192,600	63,079	38,556	90,965	\$18,734
Jun-97	429	224,820	69,206	41,866	113,748	\$21,593
Jul-97	432	220,140	70,235	43,735	106,170	\$21,191
Aug-97	440	224,280	70,697	43,043	110,540	\$21,620
Sep-97	427	216,720	61,377	39,334	116,009	\$20,841
Oct-97	355	201,780	61,594	39,663	100,523	\$19,336
Nov-97	364	204,480	37,991	64,216	102,273	\$19,524
Dec-97	378	223,200	34,368	68,629	120,203	\$21,103
Total	440	2,549,700	624,413	653,778	1,271,509	\$244,272

Natural gas is purchased from Colonial Gas under rate G-43C. Table 15 presents the natural gas consumption for the master billing account and for Building 3159.

Table 15. Air Station natural gas billing data—Colonial Gas.

Month	Master Bill Account Consumption (ccf)	Total Cost (\$)	Building 3159 Consumption (ccf)	Total Cost (\$)
Jan-96	23,079	\$19,105	4,342	\$3,585
Feb-96	21,694	\$17,961	3,452	\$2,850
Mar-96	21,634	\$17,912	3,322	\$2,743
Apr-96	16,580	\$8,993	3,346	\$1,805
May-96	7,299	\$3,987	2,442	\$1,317
Jun-96	3,045	\$1,693	1,618	\$873
Jul-96	3,489	\$1,932	1,745	\$941
Aug-96	3,054	\$1,697	1,585	\$855
Sep-96	3,143	\$1,745	1,641	\$885
Oct-96	8,503	\$7,275	2,158	\$1,834
Nov-96	13,083	\$11,167	2,862	\$2,432
Dec-96	23,607	\$20,110	4,490	\$3,815
Total	148,210	\$113,577	33,003	\$23,934

Electric savings from the fuel cell were calculated based on the fuel cell operating 90 percent of the year (1,576,800 kWh). The impact of reducing the fuel cell load due to the total Air Station load falling below 230 kW is accounted for in this 90 percent factor. Total displaced electric savings of \$143,944 were calculated as shown in Table 16.

Table 16. Building 3159 fuel cell electric savings.

	Hours/yr	Energy	Rate	Savings
Demand (Kw)		2,400	\$3.11	\$7,464
Peak (kWh)	1,880	338,400	\$0.0273	\$9,232
Low A (kWh)	2,020	363,600	\$0.0241	\$8,774
Low B (kWh)	4,860	874,800	\$0.0183	\$15,983
Fuel (kWh)	8,760	1,576,800	\$0.0650	\$102,492
Total savings				\$143,944

Several thermal interface options were evaluated for Building 3159. Fuel cell thermal utilizations ranged from 13.4 to 52.4 percent. Using the kBtu thermal savings presented in the summary table and divided into November–April and May–October groupings, the amount of natural gas that would be displaced by the fuel cell at Building 3159 was calculated using the following assumptions: a 90 percent fuel cell availability, a 75 percent boiler efficiency, and 1,000 Btu/Ccf. Table 17 lists these results.

Table 17. Building 3159 displaced boiler gas.

	Dis	placed Building	Gas*
Thermal Load Application (DHW Tank Temp. Set Point)	Nov – Apr (MMBtu)	May – Oct (MMBtu)	Total (MMBtu)
Kitchen DHW only (160 °F)	584	399	983
Non-kitchen DHW only (160 °F)	935	510	1,444
Both Kitchen/non-kitchen (160 °F)	1,519	908	2,427
Both Kitchen/non-kitchen (140 °F)	1,467	847	2,315
Space heating only (n/a)	1,484	56	1,540
DHW/space heat (160 °F)	2,516	861	3,377
DHW/space heat (140 °F)	2,952	903	3,855
*(Thermal energy utilized / 75% boiler	eff.) x 90% avail	ability x 0.001 MM	1Btu/kBtu

The site's G-43 rate is \$0.86872/Ccf for the months of November through April and \$0.50805/Ccf for the months of May through October. At 1,000 Btu/Ccf, the rates would be \$8.69/MMBtu and \$5.08/MMBtu, respectively. Table 18 presents a summary of the displaced natural gas savings for the fuel cell thermal application scenarios.

Table 18. Building 3159 thermal energy savings scenarios.

Thermal Load Application	Therm	nal Energy Sav	ings
(DHW Tank Temp. Set Point)	Nov – Apr	May - Oct	Total
Kitchen DHW only (160 °F)	\$5,077	\$2,025	\$7,102
Non-kitchen DHW only (160 °F)	\$8,119	\$2,589	\$10,708
Both kitchen/non-kitchen (160 °F)	\$13,196	\$4,614	\$17,810
Both kitchen/non-kitchen (140 °F)	\$12,747	\$4,305	\$17,052
Space heating only (n/a)	\$12,894	\$284	\$13,178
DHW/space heat (160 °F)	\$21,857	\$4,374	\$26,231
DHW/space heat (140 °F)	\$25,641	\$4,589	\$30,230

The Colonial Gas rate that would apply to the fuel cell would be its high load factor schedule, Rate G-53. The rate is \$0.85991/Ccf for the months of November through April and \$0.50680/Ccf for the months of May through October. At 1,000 Btu/Ccf, the rates would be \$8.59/MMBtu and \$5.068/MMBtu, respectively. The fuel cell would consume 14,949 MMBtu of natural gas the first year. Input fuel costs would be \$101,937 as calculated below:

\$63,745 = 7,413 MMBtu x \$8.5991/MMBtu (November–April)

\$38,192 = 7,536 MMBtu x \$5.0680/MMBtu (May-October)

\$101,937 = \$63,745 + \$38,192

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Total energy savings from the fuel cell range from \$49,109 to \$72,237:

```
$49,109 = $143,944 + $7,102-$101,937
$72,237 = $143,944 + $30,230 - $101,937
```

If natural gas could be purchased from the Defense Fuel Supply Center (DFSC) and delivered by Colonial Gas (existing distribution charge of 0.81/MMBtu) for 4.50/MMBtu, the input fuel cost would be lowered to 67,271 (14,949 MMBtu $\times 4.50/MMBtu$). This is a net savings of 34,667 over the present Colonial Gas rate schedule and contributes to a direct increase in fuel cell energy savings as follows:

```
$83,775 = $143,944 + $7,102 - $67,271
$106,903 = $143,944 + $30,230 - $67,271
```

Table 19 summarizes the fuel cell energy savings for the seven thermal utilization cases as well as for the contract gas option.

The estimated savings discussed thus far do not factor in maintenance costs, stack replacement costs, cell stack degradation, or overall lifecycle costs. An analysis was performed to show the net present value (NPV) of savings over the life of the fuel cell. NPV is the sum of future cash flows discounted at a given rate (generally a required rate of return). If NPV is positive, then the project is an acceptable investment. If NPV is negative, then the required rate of return has not been met and the project is not acceptable. Table 20 presents the input assumptions.

The fuel cell installation cost includes a new transformer and a power output controller to ensure that fuel cell electricity is not exported to the COM Electric grid. An additional \$25,000 is added for the installation of a high grade heat exchanger to interface with the space heating loop. Maintenance costs of \$18,000 are based on a commercial rate and represent approximately 1.1 cents/kWh. Stack replacement costs are based on ONSI's projection of one-third the cost of the projected commercial power plant cost of \$1,500/kW (i.e., \$1,500/kW \times 200 kW \times 1/3). A \$200,000 fuel cell rebate is available through the Department of Energy (DOE) to pay for up to one-third of the fuel cell purchase price. In the model, it was assumed that the fuel cell stack would have a life of 60,000 hours (\sim 7 years) and that stack efficiency would degrade based on operating hours.

Table 19. Building 3159 fuel cell energy savings summary.

		3-		,				
Case	ECF	2	Displaced kWh	Displaced Fuel (MMBtu)	Electrical Savings	Thermal	Nat. Gas	Net Savings
Colonial Gas								
Kitchen DHW only (160 °F)	%06	13%	1,576,800	983	\$143,944	\$7,102	\$101,937	\$49,109
Non-Kitchen DHW only (160 °F)	%06	20%	1,576,800	1,444	\$143,944	\$10,708	\$101,937	\$52,715
Both Kitchen/Non-Kitchen (160 °F)	%06	33%	1,576,800	2,315	\$143,944	\$17,810	\$101,937	\$59,817
Both Kitchen/Non-Kitchen (140 °F)	%06	32%	1,576,800	2,427	\$143,944	\$17,052	\$101,937	\$59,059
Space Heating Only (n/a)	90%	21%	1,576,800	1,540	\$143,944	\$13,178	\$101,937	\$55,185
DHW/Space Heat (160 °F)	%06	46%	1,576,800	3,377	\$143,944	\$26,231	\$101,937	\$68,238
DHW/Space Heat (140 °F)	80%	52%	1,576,800	3,855	\$143,944	\$30,230	\$101,937	\$72,237
Contract Gas								
Kitchen DHW only (160 °F)	%06	13%	1,576,800	983	\$143,944	\$7,102	\$67,271	\$83,775
Non-kitchen DHW only (160 °F)	%06	20%	1,576,800	1,444	\$143,944	\$10,708	\$67,271	\$87,381
Both kitchen/non-kitchen (160 °F)	%06	33%	1,576,800	2,315	\$143,944	\$17,810	\$67,271	\$94,483
Both kitchen/non-kitchen (140 °F)	%06	32%	1,576,800	2,427	\$143,944	\$17,052	\$67,271	\$93,725
Space heating only (n/a)	%06	21%	1,576,800	1,540	\$143,944	\$13,178	\$67,271	\$89,851
DHW/space heat (160 °F)	%06	46%	1,576,800	3,377	\$143,944	\$26,231	\$67,271	\$102,904
DHW/space heat (140 °F)	%06	52%	1,576,800	3,855	\$143,944	\$30,230	\$67,271	\$106,903
Assumptions:								
Electric Rate:	\$0.091	3 /kWh (4	werage—See (\$0.0913 /kWh (Average—See COM Electric Rate G-2)	G-2)			
Input Fuel Rate:	\$4.50-	-\$6.82 /A	1MBtu (Average	\$4.50 - \$6.82 /MMBtu (Average—See Colonial Gas Rate G-53)	as Rate G-53)			
Displaced Fuel Rate:	\$7.22-	-\$7.84 //	\$7.22 \$7.84 /MMBtu (Average-	See Colonial Gas Rate G-43)	as Rate G-43)			
Fuel Cell Thermal Output:	700,000	700,000 Btu/hour	<u>_</u>					
Fuel Cell Electrical Efficiency (HHV):	V): 36%							
Seasonal Boiler Efficiency:	75%							
ECF = Fuel cell electric capacity factor	tor							
TU = Thermal utilization								

Table 20. Building 3159 life-cycle cost-input assumptions.

Capital Cost	\$650,000
Installation cost	\$125,000*
Maintenance cost	\$18,000/yr
Stack replacement cost	\$100,000
Fuel cell rebate	\$200,000
Stack life	60,000 hr
Cycles per year	1
Escalation rates	3% per year
NPV discount rate	4%, 10%, 15%, 20%
*Add \$25,000 for installation	n of high grade heat exchanger.

The price of an ONSI PC25C fuel cell recently increased to \$850,000. Three fuel cell cost scenarios were analyzed: \$850,000, \$650,000 (new price with rebate or old price without rebate), and \$450,000 (old price with rebate). Table 21 presents 20-year IRR and NPV estimates for the high and the low thermal ranges, and two gas supplier cases presented previously in Table 19. For Colonial Gas, IRRs ranged from 0 to 10.4 percent, and NPVs ranged from \$265,029 to -\$668,348. For the DFSC scenario, IRRs ranged from 5.7 to 22.1 percent, and NPVs ranged from -\$463,978 to \$911,486.

Table 21. Building 3159 life-cycle cost summary results.

Case	F.C. Cost	IRR	NPV @ 4%	NPV @ 10%	NPV @ 15%	NPV @ 20%
Colonial	\$450k		(\$116,363)	(\$205,796)	(\$244,487)	(\$268,348)
Gas - low	\$650k	_	(\$316,363)	(\$405,796)	(\$444,487)	(\$468,348)
Thermal*	\$850k	_	(\$516,363)	(\$605,796)	(\$644,487)	(\$668,348)
Colonial	\$450k	10.4%	\$265,029	\$10,902	(\$98,022)	(\$163,711)
Gas – High	\$650k	5.1%	\$65,029	(\$189,098)	(\$298,022)	(\$363,711)
Thermal**	\$850k	2.1%	(\$134,971)	(\$389,098)	(\$498,022)	(\$563,711)
DFSC-	\$450k	16.2%	\$530,093	\$177,524	\$26,651	(\$63,978)
Low	\$650k	9.5%	\$330,093	(\$22,476)	(\$173,349)	(\$263,978)
Thermal*	\$850k	5.7%	\$130,093	(\$222,476)	(\$373,349)	(\$463,978)
DFSC-	\$450k	22.1%	\$911,486	\$394,222	\$173,115	\$40,660
High	\$650k	14.2%	\$711,486	\$194,222	(\$26,885)	(\$159,340)
Thermal**	\$850k	9.9%	\$511,486	(\$5,778)	(\$226,885)	(\$359,340)

Low Thermal = Kitchen DHW load only (160 °F)

Tables 22 through 25 show output of the lifecycle cost models for the four scenarios. Note that this analysis is a general overview of the potential savings from the fuel cell. Since detailed load energy profiles were not available, net energy savings could vary depending on actual thermal and electrical utilization.

^{**} High Thermal = Kitchen/non-kitchen DHW (140 °F) + space heating

Table 22. Building 3159 (Colonial Gas, low-thermal utilization case) 20-year life-cycle analysis.

Fuel Cell Costs	4	Fuel Cell Per	erformance	a		ğ	Operation				Financial								
kW)	\$3,250 EI	Electrical Effi	Efficiency (HHV)	HHV)		0.36 Ec	uipment L	Equipment Life (Years)		ន	Demand	Demand Savings (\$/year)	\$/vear)	7.464					
Installation Cost (\$/kW)	\$625 Overall Eff	rerall Efficient	iciency (HHV)	(`		0.73 Ca	Capacity Factor	tor		0.9	Energy S	Energy Savings (\$/year)	+	136 480					
Maintenance Cost (\$/YR.)	\$18,000 Cell Voltac	M Voltage	te (volts/cell)	 (∓	-	0.7 Cy	Cycles per Year	ear		-	Input Fut	nput Fuel Cost (\$/year)	Т	101,937					
Stack Replacement Cost (\$/kW)	\$500 C	\$500 Cycle Degradation (mV/cycle)	dation (n	nV/cycle)		9	splaced Br	Displaced Boiler Efficiency	aucy .	0.75		Thermal Savings (\$/year)		7,102					
Fuel Cell Rebate (\$/kW)	\$1,000 Operating	perating De	gradatic	Degradation (mV/1000 hrs)	00 hrs)		ermal Util	Thermal Utilization (MMBtu/yr.)	MBtu/yr.)	983.0	Inflation			0.03					
	S	Stack Life (Hours)	lours)			000'09					Fuel Escalation	alation		0.03					
	ŭ	Fuel Cell Siz	Size (kW)			500					Electric I	Electric Escalation		0.03					
	Σ	Months of Demand Reduction:	emand R	eduction.		12					NPV Dis	NPV Discount Rate	63	0.10					
Year	_	2	2	4	5	9	ľ	8	유	Ξ	12	13	14	15	16	11	<u>8</u>	6	8
Intermediate Calculations										r		-	\vdash		_		_		
Hours												H	_						_
Operation Hours/Yr.	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884 7	7,884 7,	7,884 7,	7,884 7,8	7,884 7,8	7,884 7,8	7,884 7,884	84 7,884	4 7,884	7,884	7,884	7,884
Total Operation Hours	7,884		23,652	31,536					\Box						_1	4	1		
Total Stack Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	3,072	10,956 18	18,840 26	26,724 34	34,608 42	42,492 50	50,376 58,	58,260 6,144	14,028	28 21,912	12 29,796	37,680
Degradation (V)		- 1			- 1			- 1	1	- 1			- 1		1	- 1	- 1	- 1	
Operating	0.0079		0.0079	0.0079	- 1	- 1	ı	_ 1		- 1				- 1	ı		- 1		
Cycling	0.0060	- 1	0.0060	09000	0.0060	09000	09000		0.0060		0.0060	0.0060 0.0	0.0060 0.0		0.0060 0.0060	09000 09	0900:00	09000	0.0060
Net Cell Volts	0.6861	0.6722	0.6583	0.6445	0.6306	0.6167	0.6028	0.6969	0.6770 0.	0.6632 0.	0.6493 0.	0.6354 0.6	0.6215 0.0	0.6076 0.5	0.5937 0.6879	79 0.6740	40 0.6601	01 0.6462	0.6323
Operation Values																			
Electrical Eff (%)	35.3%	34.6%	33.9%	33.1%	32.4%	31.7%	31.0%	35.5% 3	34.8% 3	34.1% 33	33.4% 32	32.7% 32	32.0% 31	31.2% 30.	30.5% 35.4%	% 34.7%	33.9%	33.2%	32.5%
Thermal Eff (%)	37.7%	38.4%	39.1%	39.9%	40.6%	41.3%	42.0%	37.5% 3		38.9% 36	39.6% AC	40.3% 41	41.0% 41		42.5% 37.6%	% 38.3%		% 39.8%	40.5%
Demand Disp. (kW)	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400 2	2,400 2,	2,400 2,	2,400 2,4	2,400 2,	2,400 2,4	2,400 2,400	0 2,400	00 2,400	0 2,400	2,400
Electric Output (MWh)	1,576.8	3	1,576.8		1,576.8	1,576.8	1,576.8	1,576.8	_	_	1,576.8 1,	~	60	_	1,576.8 1,576.8		1,576.8 1,576.8	_	8 1,576.8
Thermal Displ. (MMBtu)	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	6 0.686	983.0	983.0 96	863.0	983.0 983.0	383.0 983	0.686 0.686	0 983.0	.0 983.0	0 983.0	983.0
Fuel Input (MMBtu)	15,251	15,566	15,895	16,237	16,595	16,968	17,359	15,145	15,456	15,779 10	16,117	16,469 16	16,837	17,222 17,	17,624 15,213	13 15,526	526 15,853	53 16,193	3 16,549
Average Energy Rates										H									
Demand Rate (\$/kW)	3.11		3.30	3.40	3.50	3.61	3.71	3.82	3.94	4.06	4.18 4.	4.30 4.	4.43 4.	4.57 4.70	70 4.85	4.99	5.14	5.29	5.45
Electric Rate (\$/kWh)	9980:0	0.0892	0.0918	0.0946	0.0974	0.1003	0.1034	0.1065	0.1096 0	0.1129 0	0.1163 0.	0.1198 0.	0.1234 0.	0.1271 0.1	0.1309 0.1348	48 0.1389	389 0.1431	31 0.1474	
Gas Rate (\$/MMBtu)	7.22	7.44	99.2	7.89	8.13	8.38	8.63	8.89	9.15	9.43	9.71	10.00	10.30	10.61	10.93 11.26	6 11.59	59 11.94	4 12.30	12.67
F.C. Gas Rate (\$/MMBtu)	89.9	98.9	7.09	7.30	7.52	7.75	7.98	8.22	8.47 8	8.72 8	8.38	9.25	9.53	9.82 10	10.11 10.41	1 10.73	73 11.05	5 11.38	11.72
Fuel Cell Savings													1	1				_	\downarrow
Energy Savings (\$)		- [- 1		- 1		- 1	$\neg \tau$	_	-			\neg		-1
Demand	7,464	- 1	7,919			8,653	8,912	9	9,455	9,739	10,031			10,961		_		37 12,707	7 13,088
Energy	136,480	₩.	듸	149,135	_	158,218	162,964	167,853	စ္က	ļΩ.	83,418		_			П	പ	_	48 239,319
Displaced Fuel	7,102	7,315	7,535	1,761	7,993	8,233	8,480	8,735	8,997	9,266	9,544	9,831	10,126	10,430 10	10,742 11,065	- 1	11,397 11,739	39 12,091	
Subtotal (\$)	151,046	155,577 160,245	160,245	165,052	165,052 170,004	175,104	180,357	185,768	191,341	197,081	202,993 20	209,083 21	215,355 22	221,816 22	228,471 235,325	- 1	242,384 249,	249,656 257,146	46 264,860
Costs (\$)										٦						_		_	
Fuel Cost	101,937	4	112,706	118,588		131,475	138,539	124,497				52,369 11						_	_1
Maintenance	18,000	18,540	19,096	19,669	20,259	20,867	21,493		22,802	23,486 2	24,190 2,	24,916	25,664 26	26,434 27	27,227 28,043	- 1	28,885 29,751	51 30,644	4 31,563
Stack Replacement			_,				,	126,677	,					-	160	160,471			
Subtotal (\$)	119,937	125,704	131,803	138,258	131,803 138,258 145,095 152,342 160,032	152,342		273,311	153,663	161,095	68,958 1	77,285 1	36,110 11	95,469 20	205,405 346,927			204,881 214,903	03 225,518
Annual Savings	31,109		28,442		24,909	22,761	20,325	ᇽ	37,678	35,986 3	34,035	31,798 29	29,246 20		23,066 (111	\neg	46,973 44,7	44,775 42,242	2 39,343
Cumulative Savings	31,109	60,983	89,425	$\neg \tau$	116,219 141,128	163,890	163,890 184,215 96,671		134,349 170,335	170,335 2	204,370 2	236,167 20	265,413 29	291,760 31	314,826 203,224	-T	250,197 294,	294,972 337,214	14 376,557
Net Present Value	(405,796)			_						1	1	+	7	1			1	-	4
Int. Rate Of Return	-3.7%														-	-		-	_

Table 23. Building 3159 (Colonial Gas, high-thermal utilization case) 20-year life-cycle analysis.

2000 0000	ŀ	֓֟֟֝֟֝֟֝֟֝ <u>֚</u>							·		<u> </u>				İ		r			
ruei celi costs	+	1	ruei ceii remormance	Гепогша	2			Operation	5		+		Financial		1		_			
Capital Cost (\$/kW)	₩ ₩		Electrical Efficiency (HHV)	fficiency	(HE)		0.36	Equipm	Equipment Life (Years)	(ears)		8	Demand	Demand Savings (\$/year)	(Vyear)	7,464				
Installation Cost (\$/kW)	*		Overall Efficiency (HHV)	iciency (F	HV)		0.73	Capacit	Capacity Factor			6.0	Energy Savings (\$/year)	avings (\$	year)	136,480				
Maintenance Cost (\$/YR.)	\$18		Cell Voitage (volts/cell)	e (volts/c	ell)		0.7	Cycles	Cycles per Year		-	-	Input Fue	Input Fuel Cost (\$/year)	year)	101,937				
Stack Replacement Cost (\$/kW)			Cycle Degradation (mV/cycle)	radation (mV/cycle)		9	Displace	Displaced Boiler Efficiency	Efficiency		0.75	Thermal	Thermal Savings (\$/year)	S/year)	30,230				
Fuel Cell Rebate (\$/kW)	\$1	\$1,000	Operating Degradation (mV/1000 hrs)	Degradat	ion (mV/1	000 hrs)	2	Therma	Thermal Utilization (MMBtu/yr.)	n (MMBt.		3,855.0	Inflation		-	0.03				
		Ů,	Stack Life (Hours)	(Hours)			000'09					Т	Fuel Escalation	lation	l	0.03				
			Fuel Cell Size (kW)	Size (kW)			200				-		Electric Escalation	scalation	-	0.03	_			
	_		Months of Demand Reduction:	Demand	Reduction		12						NPV Discount Rate	ount Rate		0.10	_			
Year 1	_	7	ខ	4	2	يو	_	8		10	=	12	13	14	15	16	11	18	19	8
Intermediate Calculations					_				T	T		Γ								
Hours																			Ī	
	7,884	7,884		7,884	7,884		7,884	7,884 7	7,884	7,884 7	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7.884
ours	7,884	15,768		31,536	39,420		55,188	63,072 7	4 956'04	78,840 8	86,724	94,608	102,492	110,376 118,260	118,260	126,144	134,028	141,912	149,796	157,680
Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	3,072	10,956	18,840 2	26,724	34,608	42,492	50,376	58,260	6,144	14,028	21,912	29,796	37,680
2									_											
O.	0.0079	0.0079	0.0079					1 1								0.0061	0.0079	0.0079	0.0079	0.0079
	0.0060	09000		09000								0900.0	0900.0	0900.0		0.0060	0.0060	0900.0	0 0900 0	0900.0
	0.6861	0.6722	0.6583	0.6445	0.6306	0.6167	0.6028	0.6909	0.6770 0	0.6632 0	0.6493 (0.6354	0.6215	9/09/0	0.5937	0.6879	0.6740	0.6601	0.6462	0.6323
Operation Values																				
	35.3%	34.6%	33.9%	33.1%	32.4%		31.0%	35.5% 3	34.8% 3	34.1% 3	33.4%	32.7%	32.0%	31.2%	30.5%	35.4%	34.7%	33.9%	33.2%	32.5%
	37.7%	38.4%		39.9%	40.6%		- 1		ì							37.6%	38.3%	39.1%	39.8%	40.5%
,	400	2,400	~	2,400				_				2,400	2,400		2,400	2,400	2,400	2,400	2,400	2,400
Ť	1,576.8	1,576.8		1,576.8			1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8
(a)	3855.0	3855.0		3855.0	3855.0	\neg	_	- 1			3855.0	3855.0		- 1	3855.0			3855.0	3855.0	3855.0
	15,251	15,566	15,895	16,237	16,595	16,968	17,359	15,145	15,456 1	15,779	16,117	16,469	16,837	17,222	17,624	15,213	15,526	15,853	16,193	16,549
							_													
[3.1	82	- 1	949	3.50	3.61	3.71	Ŧ		4.06 4	4.18	4.30		4.57		4.85	4.99		j	5.45
	9980.0	0.0892		0.0946	0.0974	2	*	22	ဖွ	_)	_			_	0.1518
Gas Rate (\$/MMBtu): 7	7.84	808	_	8.57	883	9.09	Ī			_										13.75
F.C. Gas Rate (\$/MMBtu) 6.68	99.9	88. 9	60.7	230	7.52	7.75	7.98	8.22	8.47 8	8.72	8.98	9.25	9.53	9.82	10.11	10.41	10.73	11.05	11.38	11.72
Fuel Cell Savings																				
Energy Savings (\$):																				
ŀ	7,464		7,919	8,156	8,401	8,653	8,912	9,180	9,455 9	9,739	10,031	10,332	10,642	10,961	11,290	11,629	11,978	12,337	12,707	13,088
Energy:	136,480		140,574 144,792		149,135 153,609	158,218	162,964	167,853	172,889 178,075 183,418 188,920 194,588	78,075 1	183,418	188,920	194,588	200,425	200,425 206,438 212,631	212,631	219,010	225,581	232,348	239,319
uel:	30,230	31,137	32,071	33,033	34,024	35,045	960'98	37,179	38,294 3	39,443 4	40,627	41,845	43,101	44,394	45,726	47,097	48,510	49,966	51,465 5	53,008
	174,174	179,399	184,781	190,325	196,034	201,915	207,973	214,212	220,638 2	227,258	234,075 241,098 248,330	241,098		255,780 263,454	263,454	271,357	279,498	287,883	296,520	305,415
Fuel Cost:	101,937	107,164	107,164 112,706 1	118,588		31,475	138,539	124,497	130,861	137,609 144,768 152,369	44,768		160,446 169,036	169,036	178,178 158,413	158,413	166,526	175,130	184,259 1	193,954
	18,000	18,540	19,096	19,669	20,259	20,867	21,493		22,802	23,486 2	24,190	24,916	25,664	26,434	27,227	28,043	28,885	29,751	30,644	31,563
cement:						,		126,677								160,471	-	-		
	119,937	125,704	131,803	138,258	145,095	152,342	160,032	273,311 153,663 161,095 168,958 177,285 186,110 195,469 205,405 346,927	53,663 1	61,095	856,89	177,285	186,110	195,469	205,405	346,927	195,411	204,881	214,903 2	225,518
	54,237	53,696	53,696 52,979 52,067 50,940 49,573 47,941	52,067	50,940	49,573	47,941	926'99) (66'65)	66,976 66,163 65,117 63,812 62,221 60,311 58,049 (75,569)	6,163 6	55,117	53,812	52,221	50,311	58,049	(75,569)	84,087	83,002	81,616 7	79,898
vings:	54,237		160,911	212,978	263,918	313,491	361,432	302,333	89,309 4	35,472 5	900,589	564,401	526,621	586,932	744,982	569,412	753,499	836,501	918117	998,015
	(189,098)																			
Int. Rate Of Return 5	5.1%																_	_		ı

Table 24. Building 3159 (contract gas, low-thermal utilization case) 20-year life-cycle analysis.

Particulation SE2 Secure Control	First Call Costs	-		Enol Col	Borform				٤								-		Γ		
Section	Capital Cost (\$/kW)	\$3 250		Flectrics	Ffficience	(HHV)		92,0		inmont life	(Voore)		٤		Clair	Confebroor	7 464		Ŧ		
SECONO Carl Voltage (voltage) Displayed Boine Efficiency Displayed Boine Dis	Installation Cost (\$/kW)	\$625		Overall	fliciency	HHX		0.73	3 6	acity Facto	2000		000		Saving	S (Shear)			T		
BSXOD Check Departation (mV/1000 bas) Exponoration (mV/1000 bas) Exponoration (mV/1000 bas) Displaced Board (mV/1000 bas)<	Maintenance Cost (\$/YR.)			Cell Volt	age (volts	(Sell)		0.7	Š	es per Ye			_	hou	Fuel Cos	1 (S/vear)	Т		Τ		
Signot Department (NY) (1000 hrs Engineering 1010 Engineering 1010 Engineering 1010 Engineering	Stack Replacement Cost (\$/k\)			Cycle De	gradation	(mV/cycle	(9	Dist	laced Boil	er Efficier)C	0.75	Ther	nal Savin	os (\$/vear			Τ		
State Line Fuel Cell State (MV) Evolution Evol	Fuel Cell Rebate (\$/kW)	\$1,000		Operatin	g Degrad	ation (mV/	000 hrs)	2	The	rmal Utiliza	ation (MM	Btu/yr.)	983.0	Inflat	6		1		1		
Fall Cold Stream Market Robert Cold Stream Market Ro		-		Stack Lif	e (Hours)			000'09						Fuel	Escalatio	,	0.03				
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negy Fales 1 2.0 3.40 3.60 3.61 3.71 3.82 3.94 4.06 4.18 4.30 4.57 4.70 4.85 4.99 nd Rale (\$AWN) 3.11 3.20 3.30 3.40 3.60 3.71 3.82 3.94 4.06 4.18 4.30 4.57 4.70 4.85 4.99 nc Rale (\$AMNIbu) 0.0866 0.0892 0.0946 0.074 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103 0.103	Fuel Input (MMBtu)	15,251	15,566			16,595	- 1													16,193	16,549
Action (\$ANW) 311 3.20 3.30 3.40 3.50 3.61 3.71 3.82 3.94 4.06 4.18 4.30 4.43 4.57 4.70 4.85 4.99 Ichale (\$ANW) 0.0866 0.0892 0.0974 0.1003 0.1034 0.1129 0.1129 0.1134 0.1234 0.1271 0.1309 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 <td>Average Energy Rates</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>_</td> <td></td>	Average Energy Rates										_										
Cralle (\$AMMBlu) 7.22 7.44 7.66 7.89 8.13 8.38 8.63 8.89 9.15 9.43 9.71 10.00 10.30 10.134 0.1349 0.1348 0.1365 0.1348 0.1055 0.1234 0.1234 0.1234 0.1234 0.1234 0.1234 0.1234 0.1234 0.1349 0.1349 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348 0.1348	Demand Rate (\$/kW)	3.11	3.20	\neg	3.40	3.50														5.29	5.45
Sas Rate (\$MMBlu) 7.22 7.44 7.66 7.89 8.13 8.38 8.63 9.15 9.37 9.71 10.00 10.30 10.61 10.93 11.26 11.59 Sas Rate (\$MMBlu) 4.1 4.54 4.68 4.82 5.11 5.27 5.42 5.59 5.76 5.39 6.11 6.29 6.48 6.67 6.87 7.08 Sanings Assa 1.64 1.68 5.11 5.27 5.42 5.59 5.76 5.39 6.11 6.29 6.48 6.67 6.87 7.08 Assa 1.40 4.68 4.91 8.156 8.401 8.653 8.912 9.739 10.031 10.322 10.641 11.290 11.529 11.578 Ind 7.102 7.315 7.544 14.732 18.630 158.218 18.036 18.244 9.831 10.031 10.042 10.240 11.250 10.041 10.042 10.042 10.042 10.042 10.042	Electric Rate (\$/kWh)	0.0866	0.0892	<u>8</u>		0.0974				_											0.1518
Sas Rale (\$MMBlb) 411 4.54 4.66 4.96 5.11 5.59 5.76 5.93 6.11 6.29 6.48 6.67 6.87 7.08 Savings Savings 4.54 4.66 4.96 5.11 5.27 5.42 5.59 5.79 6.11 6.29 6.48 6.67 6.87 7.08 Savings 4.54 4.66 8.156 8.401 8.653 8.912 9.180 9.455 9.739 10,031 10,332 10,642 10,561 11,290 11,678 11,978 nd 7.464 7.680 1.45,721 1.45,721 1.45,721 1.62,361 1.62,361 11,678 11,678 11,678 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978	Gas Rate (\$/MMBtu)	7.22	7.44	7.66	7.89	8.13															12.67
Savings Nings (\$) 7.464 7.688 7.319 8.156 8.401 8.653 8.912 9.180 9.456 9.739 10.031 10.332 10.642 10.642 10.961 11.290 11.629 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.978 11.988 11.978 11.978 11.978 11.978 11.978 11.978 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.988 11.9	F.C. Gas Rate (\$/MMBtu)	4.41	4.54	4.68	4.82	98													7.29	7.51	7.73
numage (§) 7. 464 7. 688 7.919 8.156 8.401 8.653 8.912 9.180 9.456 9.739 10.031 10.332 10.642 10.961 11.290 11.629 11.978 1. 136.480 140,574 144,792 148,135 153.699 158,218 162.984 167.883 178,075 183,418 188,920 194,568 200,425 206,438 212,631 219,010 toole Fuel 7,102 7.315 7.535 7.761 7.993 8.233 8.480 8.735 8.997 9.266 9.544 9.831 10,126 10,420 10,742 11.065 11.397 tall (\$)	Fuel Cell Savings		4						_			_		\dashv							
nd 7,464 7,684 7,684 7,684 7,684 7,695 10,332 10,632 10,532 10,642 10,392 11,290 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,978 11,078 10,332 10,425 11,978 11,978 10,128 10,128 10,425 11,978 11,978 10,128 10,128 10,425 11,970 11,978 10,128 10,128 10,425 10,042 10,128 11,970 11,978 10,128 10,128 10,128 10,128 11,970 11,970 10,128 10,128 10,128 10,128 10,128 10,138 10,138 11,970 11,970 10,128 10,128 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138 10,138	Energy Savings (\$)											_		_	1						
tyle 136.480 140,574 144,792 149,135 153.609 150,436 178,075 183,416 188,920 194,586 200,425 206,425 205,131 191,010 roced Fuel 7,102 7,315 7,535 7,761 7,933 8,233 8,480 8,736 19,266 9,544 9,831 10,126 10,420 10,742 11,065 11,397 rock: 151,046 155,577 160,245 165,052 170,004 175,104 180,357 185,768 100,156 10,420 10,742 11,065 11,397 chall 151,046 165,057 170,100 175,104 180,357 185,768 100,156 10,420 10,742 11,065 11,397 chall 151,046 180,000 18,200 19,669 20,293 20,149 100,553 100,553 105,883 111,551 11,551 11,566 11,040 10,400 100,883 100,883 11,551 11,566 11,040 100,883 11,541 <td< td=""><td>Demand</td><td>7,464</td><td>7,688</td><td>7,919</td><td></td><td>8,401</td><td>8,653</td><td>8,912</td><td></td><td>455 9,</td><td>739</td><td>100</td><td>332 10</td><td>,642</td><td>- - - - - -</td><td>- [</td><td>1,629</td><td></td><td></td><td>12,707</td><td>13,088</td></td<>	Demand	7,464	7,688	7,919		8,401	8,653	8,912		455 9,	739	100	332 10	,642	- - - - - -	- [1,629			12,707	13,088
Local Fuel 7,102 7,535 7,761 7,983 8,283 8,266 9,266 9,544 9,831 10,126 10,430 10,742 11,365 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 10,126 10,426 10,430 10,742 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397 11,397	Energy	136,480	140,57	144,79	149,135	153,609	158,218	162,964		72,889 1.	8,075	3,418 18	88,920 19	4,588 20	0,425 20		12,631			232,348	239,319
Lad (\$) 151,046 155,577 166,245 165,052 170,004 175,104 180,357 185,768 191,341 197,081 202,993 209,083 215,355 221,816 228,471 235,325 242,384 203t. Local Color Colo	Displaced Fuel	7,102	7,315	7,535	7,761	7,993	8,233	8,480	3,735	1									11,739	12,091	12,453
Dost: 67,271 70,720 74,378 78,260 82,382 86,764 91,425 82,159 86,359 90,812 95,536 100,553 105,883 111,551 117,585 104,541 109,895 enance: 18,000 18,540 19,096 19,669 20,259 20,867 21,493 22,138 22,802 23,486 24,190 24,916 25,664 26,434 27,227 28,043 28,085 Reparement:	Subtotal (\$)	151,046	155,57	7 160,24	5 165,052	170,004	175,104	180,357	185,768		7,081 20	2,993 20	9,083 21	5,355 22	1,816 22		35,325			257,146	264,860
Fig. 271 Fig. 272 Fig. 273	Costs (\$)		_	_		-r				$\overline{}$											
18,000 18,540 19,086 19,669 20,259 20,867 21,138 22,802 23,486 24,916 25,684 26,434 27,227 28,043 28,885 28,885 nent: - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -	Fuel Cost:	67,271	70,720	$\overline{}$	_	1				$\overline{}$		_	0,553 10	5,883 11	1,551	\neg	04,541	109,895		121,598	127,996
nent:	Maintenance:	18,000	18,540				- 1		$\overline{}$	\neg	- 1									30,644	31,563
85,271 89,260 93,474 97,329 102,642 107,631 112,918 230,973 109,161 114,296 119,727 125,469 131,546 137,985 144,811 293,055 138,780 35: 65,775 66,377 66,771 67,123 67,362 67,473 67,408 (45,206) 82,183 83,266 83,614 83,809 83,831 83,659 (57,730) 103,604 401,862 65,775 122,052 198,863 265,986 333,348 400,821 468,259 423,053 588,016 671,283 754,897 838,706 922,537 1,006,197 948,466 1,052,071 948,466 1,052,071	Stack Replacement:		_	-		,	,		. 126,677		·	-			•		60,471			-	
5: 65,775 66,371 66,771 67,123 67,362 67,473 67,438 (45,206) 82,183 83,266 83,614 83,809 83,831 83,659 (57,730) 103,604 400,822 67,475 132,092 198,863 265,986 333,348 400,821 468,259 423,053 588,016 671,283 754,897 838,706 922,537 1,006,197 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,466 1,052,071 948,4	Subtotal (\$):	85,271	89,260	93,474	97,929		107,631	112,918	230,973	19,161	4,298 11	19,727 1	25,469 13	1,546 13	7,985 14		293,055	138,780	145,324		159,559
inings: 65,775 132,092 198,863 265,986 333,348 400,821 468,259 423,053 505,233 588,016 671,283 754,897 838,706 922,537 1,006,197 948,466 1,052,071 [22,476]	Annual Savings:	65,775	66,317	66,771	67,123	67,362	67,473	67,438	45,206) 8	2,180 8	783 8	3,266 8	3,614 83	808	,831 8		57,730)	103,604	104,332	104,904	105,301
	Cumulative Savings:	65,775	132,09	2 198,86	3 265,986	333,348	400,821	468,259	123,053 5	05,233 50	38,016 67	71,283 7	54,897 83	8,706 92	2,537 1,	006,197	348,466	1,052,071	1,156,403	1,261,307	1,366,608
	Net Present Value:	(22,476)	_	_	_									_							
	Int. Rate Of Return	9.4%		_								-									

Table 25. Building 3159 (contract gas, high-thermal utilization case) 20-year life-cycle analysis.

| Fuel Cell Costs | Fuel Cell Performance | | Operation | Financial |

i dei deil dosts	4					-	2	Operations			_	Linalica		-						
Capital Cost (\$/kW)	\$3.	250 Elec	\$3,250 Electrical Efficiency (HHV)	H) Kouek	(AH	0	0.36 Equ	Equipment Life (Years)	(Years)		20 02	emand Sa	Demand Savings (\$/year)	ar) 7,464	_					
Installation Cost (\$/kW)	€3	750 Over	\$750 Overall Efficiency (HHV)	ncy (HH)	6	0	0.73 Cap	Capacity Factor	ı		0.9 E	nergy Sav	Energy Savings (\$/year)	136,480	9					
Maintenance Cost (\$/YR.)	\$18,	\$18,000 Cell Voltage	Voltage ((volts/cell)		0	0.7 Cyc	Cycles per Year	ľ		1) but Fuel	Input Fuel Cost (\$/year)	67,271	T					
Stack Replacement Cost (\$/kW)		500 Cycl	\$500 Cycle Degradation (mV/cycle)	ation (m)	//cycle)	9		Displaced Boiler Efficiency	r Efficienc	6	0.75 T	hermal Sa	Thermal Savings (\$/year)		Τ_					
Fuel Cell Rebate (\$7kW)	\$1,0	900 Ope	rating De	gradation	\$1,000 Operating Degradation (mV/1000 hrs)) hrs) 2		Thermal Utilization (MMBtu/yr.)	tion (MME		3,855.0 Inflation	nflation			Γ					
		Stac	Stack Life (Hours)	urs)			00000				F	Fuel Escalation	tion	0.03						
		Fuel	Fuel Cell Size (kW)	e (kW)		2	200				E	Electric Escalation	alation	0.03						
	_	Mon	Months of Demand Reduction:	mand Re	duction:	\dashv	12					NPV Discount Rate	ınt Rate	0.10						
Year	_ Z	l	[E	Ē		٩		8	5	=	12		13	14	15	16	12	<u>8</u>	19	8
Intermediate Calculations											-									
	П						П			П										
	[\neg	1												7,884		7,884	7,884	7,884	7,884
SINC	П	\neg	- 1			- 1	- 1						ا۔۔		118,260	126,144	134,028	141,912	149,796	157,680
Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	3,072	10,956	18,840 26	26,724 3	34,608	42,492 5	50,376	58,260	6,144	14,028	21,912	29,796	37,680
0	- 1											- 1	Ĺ	- 1			ŀ		- 1	
Operating	ı		- 1	- 1	- 1			- 1				- 1		- 1	6200:0		0.0079	0.0079	0.0079	0.0079
	ı	- 1			- 1	1	ı	ŀ						0.0060	0900:0		0.0060	0.0060		0900.0
	0.6861 0	0.6722	0.6583	0.6445	0.6306	0.6167	0.6028	0.6909	0.6770 0.	0.6632 0.	0.6493 0.	0.6354	0.6215 0	0.6076	0.5937	0.6879	0.6740	0.6601	0.6462	0.6323
					1															
)		34.6%	33.9%		32.4%	31.7%		35.5% 3		34.1% 33	33.4% 33	32.7%	32.0% B	31.2%	30.5%	35.4%	34.7%	33.9%	33.2%	32.5%
Thermal Eff (%)	37.7% 3	38.4%	39.1%	1	40.6%	41.3%	42.0%	37.5% 3	38.2% 38	38.9% 36	39.6% 40	40.3%	41.0%	41.8%	42.5%	37.6%	38.3%	39.1%		40.5%
kW)	2,400 2	2,400	2,400	2,400	2,400	2,400		2,400 2	2,400 2,	2,400 2,	2,400 2,	2,400	2,400 ½	2,400	2,400	2,400	2,400	2,400	2,400	2,400
									\neg					1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8
Thermal Displ. (MMBtu) 3			- 1		3855.0	- 1	- 4	3855.0 3	3855.0 38		3855.0 38		3855.0 3	3855.0	3855.0		3855.0	3855.0	3855.0	3855.0
Fuel Input (MMBtu)	15,251	15,566	15,895	16,237	16,595	16,968	17,359	15,145	15,456 18	15,779 16	16,117	16,469	16,837	17,222	17,624	15,213	15,526	15,853	16,193	16,549
Average Energy Rates																				
Demand Rate (\$/kW)	3.11		3.30	3.40	3.50	3.61	3.71	3.82	3.94	4.06	4.18	4.30	4.43	4.57	4.70	4.85	4.99	5.14	5.29	5.45
(0.0866 0	0.0892	8	0.0946	0.0974	0.1003	0.1034	0.1065 0	0.1096 0.	0.1129 0.	0.1163 0	0.1198	0.1234 0	0.1271	0.1309	0.1348	0.1389	0.1431	0.1474	0.1518
	7.84 8		8.32			60.6		9.64		10.23	10.54	10.85	11.18	11.52	11.86	12.22	12.58	12.96	13.35	13.75
(a)	4.41	4.54		4.82	4.96	5.11	5.27	5.42 5	5.59 5.	5.76 5.	5.93 6.	6.11	6.29	6.48	6.67	6.87	7.08	7.29	7.51	7.73
Fuel Cell Savings																				
Energy Savings (\$)		П	- 1	- 1		- 1	ı	ı	ı			- 1								
	7,464 7	889'4	_	8,156	8,401	8,653	8,912		9,455 9,	9,739	10,031	• 1	\neg		11,290		11,978	12,337	٠ [13,088
	136,480 140,574 144,792	40,574			153,609	153,609 158,218 162,964	62,964			78,075 16	33,418 1	- 1	\prod		206,438	_	219,010	225,581	232,348	239,319
inel	30,230	31,137	- 1	33,033	34,024	35,045	960'96	37,179 3	38,294 39	39,443 40	40,627 4		- 1		45,726		48,510	49,966	51,465	53,008
Subtotal (\$)	174,174 179,399 184,78	79,399	184,781	190,325	196,034	201,915	507,973	190,325 1196,034 201,915 207,973 214,212 220,638 227,258 234,075 241,098	20,638 23	27,258 23	34,075 2		248,330	255,780	263,454	271,357	279,498	287,883	296,520	305,415
	- 1	- 1	- 1	- 1	- 1	•		- 1	- 1		-		\neg	- 1						
Fuel Cost	- 1	- 1						- 1				100,553	105,883	111,551	117,585	104,541	109,895	115,573	121,598	127,996
	18,000	18,540	19,096	19,669	20,259	20,867	21,493		22,802 23	23,486 24	24,190 2	24,916	25,664	26,434	27,227	28,043	28,885	29,751	30,644	31,563
Stack Replacement -								126,677	-	_	_					160,471				
Subtotal (\$)	85,271 8		- 1	97,929	102,642	102,642 1107,631 112,918 230,973	112,918	230,973 1	109,161	114,298 119,727 125,469	19,727	25,469	131,546	137,985	144,811	293,055	138,780	145,324	152,242	159,559
Annual Savings	38,903 9	90,139		95,396	93,393	94,284	35,055	(16,761) 1	11,478 1	12,960 11	14,349	15,629	16,784	17,796	118,643	(21,698)	140,718	142,559	92,396 93,393 94,284 95,055 (16,761) [111,478 [112,960 [114,349 [115,629 [116,784 [117,796 [116,643 [(21,698) [140,718 [142,559 [144,278 [145,856	145,856
vings	88,903 179,042 270,349	79,042		362,745	456,138	550,422	345,477	628,715 7	40,193 8	53,153 96	57,501 1,	083,130	199,914	,317,710	1,436,352	1,414,655	1,555,373	1,697,932	1,842,210	1,988,06
	194,222	1						1	1	1	1		1							
Int. Rate Of Return	14.2%								1	1										

4 Conclusions and Recommendations

This study concluded that Building 3159 at the U.S. Coast Guard Air Station Cape Cod, MA was the only viable site for fuel cell installation. It was recommended that the fuel cell electrical interface at this building be made through a new 300 kVA transformer tied into either the 208/120 V panel in the electrical room or the 4160 V side of the existing building transformer. Fuel cell electrical output not used at Building 3159 would go into the Air Station base grid.

Several thermal interface options were evaluated. These included DHW for the kitchen, DHW for the residents, and space heating for the entire building. Supplying all three loads resulted in the highest fuel cell thermal utilization (52 percent) versus supplying only the kitchen DHW (13 percent). Interfacing with the space heating load or maintaining the DHW tank at its current 160 °F would require the installation of a high grade heat exchanger option for the fuel cell.

There is space available for locating the fuel cell just outside the mechanical room. Thermal piping runs are relatively short. The electrical interface would be approximately 100 ft over to the existing transformer.

Energy savings for eight thermal interface options and two input fuel suppliers were calculated. Annual energy savings ranged from \$49,109 to \$72,237 for the Colonial Gas cases and \$83,775 to \$106,903 for contract gas purchases through D.F.S.C cases.

Lifecycle costs showed 20-year IRRs of between zero and 12 percent based on a fuel cell cost of \$650,000 (current cost of fuel cell less \$200,000 rebate).

Appendix: Fuel Cell Site Evaluation Form

Site Name: U.S. Coast Guard Air Station Cape Location: New London, CT	Cod Contacts: Jim Candee
1. Electric Utility: COM Electric/Narragansett	Rate Schedule: G-2
2. Gas Utility: Colonial Gas	Rate Schedule: G-43
3. Available Fuels: Natural gas, diesel	
4. Hours of Use and Percent Occupied:	Weekdays hrs Saturday hrs Sunday hrs
 Outdoor Temperature Range: Design dry bulb temperatures: 14 °F to 79 ° Extremes: 11 °F to 85 °F 	F
6. Environmental Issues: No major issues and	ticipated.
7. Backup Power Need/Requirement: Three b	ackup generators at Air Station.
8. Utility Interconnect/Power Quality Issues: Interconnection needs to be evaluated. Tot sometimes.	
9. On-site Personnel Capabilities: Plant main	tenance personnel.
10. Access for Fuel Cell Installation: Access a	available from street and parking area.
11. Daily Load Profile Availability: Electric Io	ead data to be provided by COM Electric.
12. Security: Base to decide on fence surroun	ding fuel cell.

Site Layout

Facility Type: Barracks

Age: 26 years

Construction: Concrete block with brick fascia. Exterior insulation just installed.

Square Feet: 36,700 sq ft

See Figures 1 & 2

Show:

electrical/thermal/gas/water interfaces and length of runs drainage building/fuel cell site dimensions ground obstructions

Electrical System

Service Rating: 4160 V distributed on base grid

4,160/208 V, 300 kVA transformer at Building 3159

COM Electric 1,000 kVA transformer feeds Air Station area.

Electrically Sensitive Equipment: N/A.

Largest Motors (hp, usage): N/A.

Grid Independent Operation?: Possible application. Decision to be made by base.

Steam/Hot Water System

Description: Two low-pressure steam boilers.

System Specifications: Kewanee 5 MMBtu/hr

Weil-McLain 320,000 Btu/hr.

Fuel Type: Natural gas.

Max Fuel Rate:

Storage Capacity/Type: 1600 gal

Interface Pipe Size/Description:

End Use Description/Profile: Kewanee boiler operates during heating season. Steam used to heat 1600-gal hot water storage tank to 160 °F.

Space Cooling System

Description: Several window A/C units.

Air Conditioning Configuration:

Type: Rating: Make/Model:

Seasonality Profile:

Space Heating System

Description: Hydronic heating loop feeds individual heats throughout buildings.

Fuel: Natural gas.

Rating:

Water supply Temp: 100 – 180 °F, 11 psi steam.

Water Return Temp: 90 – 160 °F condensate return.

Make/Model:

Thermal Storage (space?): N/A

Seasonality Profile: Space heating provided from about 15 October to sometime in April. Large boiler operates in winter; small boiler operates in summer.

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other fuels. Researchers at the U.S Laboratory (CERL) have actively 1993 (FY93). CERL selected and operation and maintenance of fuel cell power plants and their therma	s. Army Engineer Rese- participated in the deve- evaluated application s cells, and compiled "le I interfaces installed at S. Coast Guard Acader	arch and Development elopment and applicati ites, supervised the de- essons learned" for fee Department of Defens my, New London, CT,	Center (ERDC), on of advanced f sign and installat dback to manufa e (DoD) location	ricity and heat from natural gas and Construction Engineering Research uel cell technology since fiscal year ion of fuel cells, actively monitored the cturers of commercially available fuel s. This report presents an overview of ceptual fuel cell installation layout and
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